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Transit in the land of plenty:
A case for linking land use patterns and public transit service planning

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Transit in the land of plenty:
A case for linking land use patterns and public transit service planning

by

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Abstract

Transit in the land of plenty:
A case for linking land use patterns and public transit service planning

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This professional report examines academic literature on needs-gaps analyses in transit planning and proposes that this methodology ignores the basic premise of transit planning which is to serve a region and respond to land uses. The report proposes identifying land use patterns in Dallas County, TX for improved transit service. The research incorporates land use into needs-gaps analyses to test the relevancy of this proposal.

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Chapter 1: Introduction

Since the early 2000s, needs-gaps analyses have proliferated in academic research as mechanisms for measuring accessibility and transit access across cities. Needs-gaps research aims to identify “spatial gaps” in public transport networks by measuring transit supply –number of transit stops, distance to nearest transit line, sidewalk access, etc. - against transit demand, which usually is a population count or density measure in any given spatial unit (Currie, 2010). The proliferation of websites such as the Center for Neighborhood Technology’s AllTransit app and TransitDeserts.net census-tract based mapping tools have made quick analysis of transit service in neighborhoods across American cities widely available to professional planners and community members (Center for Neighborhood Technology, 2018; The Urban Information Lab, 2018).

This professional report examines different needs-gaps tools and methodologies for performing analyses to consider their performance for equity measurements and general public transit efficacy and proposes a land-use based alternative. I argue that needs-gaps analyses are of limited utility due to the very nature of public transit objectives – which is to serve a region, and not individual census tracts across a service area. Furthermore, analyzing granularized census tract data for disadvantaged populations does not create a meaningful measure of public transit access or accessibility.

Land use and density is of utmost important to the efficacy of public transit routes because these factors can help to serve a greater number of people. This paper reviews existing literature on needs-gaps analyses and proposes that analyzing land use conditions is more relevant to transit planning. The research is focused on analyzing land uses in Dallas County, Texas to examine if there is a spatial mismatch between current transit conditions and land use patterns in Dallas County or if public transit appears to be serving the region's needs appropriately.

Chapter 2: Literature and Tools Review

There are two terms that researchers and practitioners use in relationship to equity analysis in transit planning – horizontal equity and vertical equity (Delbosc, 2011). While these terms frequently appear in literature, they are frequently misinterpreted and thus are problematic because they are not applied accurately. Delbosc writes that "horizontal equity (fairness or egalitarianism) is concerned with providing equal resources to individuals or groups considered equal in ability. It avoids favoring one individual or group over another and services are provided equally regardless of need or ability," (Delbosc, 2011, pg. 1252) and thus, it actually looks like *equality* more than equity. Horizontal equity is an equal distribution of shared resources across all populations with no consideration for protected classes. Vertical equity, on the other hand, "is concerned with distributing resources between individuals of different abilities and needs" (Delbosc, 2011, pg. 1252). With vertical equity, the goal is to provide transit service to those with the greatest need in a community. "Greatest need" has been interpreted in a variety of capacities in both research and practice – those with greatest need may be the elderly, or youth, or low-income, or households with no vehicle access. Still, a lot of equity analysis looks more like horizontal equity analysis in that it is concerned with providing equal access across a service area region. Furthermore, the U.S. Department of Transportation undermines equity in its definition of transit service provision and equity analysis: [Public transit is tasked with] "providing equal levels of service to minority and non-minority residents of the urbanized area " (Transit Cooperative Research Program, 1997, p. 18). What the USDOT effectively sanctions in equity analysis is actually *equality* or horizontal equity.

Another consideration with transit provision is density and land use. Since density varies considerably across American cities, transit that serves high density areas supports more people and activities than transit in low-density areas. Providing more service per capita in low density areas in fact undermines vertical equity since most low-density places are higher-income suburbs. Yet there are strong political forces that frequently spread transit service across regions. Needs-gaps analyses frequently do not account for area densities but can retrench service provision across all spatial units regardless of the density or land use surroundings.

The nascent field of transit needs-gaps analyses is widely cited to have originated with Graham Currie's 2004 article, which attempts to evaluate the public transit performance in Hobart, Australia for disadvantaged populations by measuring supply (transit service measurements like stops, routes, etc.) and demand (populations and households) across census tracts (Currie G. , 2004). Since then, both academic literature and professional practice have expanded to embrace the needs-gaps analysis for public transit with various measures for transit supply and ridership demands (Center for Neighborhood Technology, 2018; The Urban Information Lab, 2018; Al Mamun, 2011; Foth, 2013; Golub, 2014; Fransen, 2015; Jaramillo, 2012; Jiao, J. and Dillivan, M., 2013; Jiao J., 2016; Murray, 2003).

The current academic literature on needs-gaps analyses has sizeable inconsistencies in the data and methods employed. Researchers use varying indices to measure transit supply and demand. In needs-gaps studies where equity analysis is the focus, researchers will often select a disadvantaged population to analyze for the rider demand portion of the equation – riders such as the elderly, youth, disabled, zero-vehicle households, low-income, etc. Unfortunately, all of these studies use different metrics to measure disadvantage. Just as there is no consistency among researchers for the methodology used for measuring demand, the same problems persist with the transit supply measures employed. A summary of the needs-gaps studies, the data and methods employed for each of them is found in Table 1.

Location also matters since some studies utilize U.S. Census data (Jiao J. et al., 2013) (Jiao J., 2016), while other studies are conducted abroad and utilize those federal governments' datasets – ranging from Australia (Currie, 2004) (Currie, 2010) to Flanders, Belgium (Fransen, 2015) to Toronto, Canada (Foth, 2013). Furthermore, the accessibility of public transit in densely populated places like Flanders, Belgium or Santiago de Cali, Colombia, or Toronto, Canada may be far more convenient than any American transit system, so measures like zero-vehicle households may not be applicable to measuring disadvantage in those cities.

A summary of the literature reviewed follows:

Table 1: Summary of needs-gaps studies, the supply and demand measurements in each study, and the findings. Note the inconsistencies in data and methods across the studies.

Study	Area studied	Demand measurement	Supply measurement	Findings
Currie (2010)	Melbourne, Australia	• "Australian Bureau of Statistics Index of Relative Socio-Economic Advantage/Disadvantage" • a transport needs index	• Bus and tram stops • Public transit service frequency for each stop/station that measured the 'total number of service arrivals per week' • Walk catchments for each stop/station were measured by distance thresholds	Transit coverage and supply was greater in the inner city, and sparser in the fringe suburban areas. He found that 8.2% of Melbourne residents have high transit needs but have access to zero or very low transit supply – these residents live predominantly in suburban fringe areas of Melbourne.

Table 1 (cont.)

Jaramillo (2012)	Santiago de Cali, Columbia	• Population over 16 years of age without access to private • Population over 60 years of age • Population with disabilities • Population without work • Number of students • Population belonging to low and very low strata of income • Children Under 5s, not included in the statistics of mobility and who, moreover, require accompaniment of an adult by law • Illiterate population	• Total number of stops in each district • Capacity of the vehicles • Average frequency of service for each stop • Total area of the district	Districts with the greatest socio-economic disparities correspond with the greatest gaps in transit service in the city. Disadvantaged districts are more likely to be distant from the city center. City center districts had an over-supply of transit service.

Table 1 (cont.)

Foth et al. (2013)	Toronto, Canada	• median household income, • percentage of labor force that is unemployed, • percentage of population that has immigrated within the last 5 years, and • percentage of households that spend more than 30% of income on housing rent.	• origin-destination data for all workers in the Toronto region at the census tract level (Statistics Canada). • Compared accessibility and transit travel times	The most socially disadvantaged census tracts are located in geographically diverse areas of the city. Trend of suburbanization of poverty in Toronto between 1996-2006 (period of study). Still disadvantaged populations have the most transit benefits in the region during the 10-year period.
Murray & Davis (2001)	Columbus, Ohio and Queensland, Australia	• Under 16 years old • Senior citizens • Low-income • Migrants and Overseas Visitors • Single or no car households • Disability	• evaluates areas not served by existing transit stops to extend transit coverage to reach a larger population. • also concerned with reducing transit stop redundancy	Eliminate and relocate some stops to extend service access and increase accessibility.

Table 1 (cont.)

Fransen et al. (2015	Flanders, Belgium	• Percentage of the population aged 65 and older • Percentage of the population aged 6-11 years old • Percentage of households without privately owned vehicles • Percentage of the active population that is unemployed	• modeled the transit network utilizing GTFS data, to create an Index of Public Transport Need (IPTN), which represented the spatial distribution of the tested socio-demographic groups for each TAZ. • created an Index of Public Transport Provision (IPTP), which represented the availability of public transportation for each TAZ.	Suburban/peripheral rural areas have the largest transit gaps in Flanders region.

A supply metric that is frequently employed in needs-gaps studies is the number of bus stops in the spatial unit studied. The number of bus stops shouldn't influence a supply measure since more stops in a census tract/district/block group does not necessarily mean better service. In fact, some practitioners are encouraging wider spacing optimization of 400 meters between stops (Walker, 2010). One disadvantage demand measure that is problematic is zero-vehicle households since there are households who choose to use transit but could otherwise afford to own a vehicle.

Predictably, most of the studies found that the greatest transit gaps are in outlying, suburban areas of the cities studied. Questions that transit agencies must consider include: Is it a good use of public resources to bring transit to low-density outer suburban rings of a city where there may be fewer employment opportunities and low-density residential housing? Does every census tract need to be served equally? Should transit provision be centered on increasing ridership or decreasing travel times? What about increasing headway times for routes that are currently served? In the needs-gaps universe, how does one account for tracts where there are few residences or employment opportunities? The needs-gaps analysis focuses on equality – or providing equal service across every spatial unit measured in a service area – and since not every census tract is created equally, is an inadequate tool for analysis. Equal service across every spatial unit measured would mean that the transit supply matched the transit demand of potential ridership in that area.

There are a myriad of reasons why a census tract or spatial unit may have high provision but low needs. For example – industrial areas may not have any residents, but may provide jobs, therefore, there is still a rationale for bringing workers to those areas. Furthermore, transit routes that pass through areas with low-demand measures in order to serve areas of high demand will reflect an over-supply in the census tract, but the results are misleading because the point is to get riders to the area of high demand. Inversely, low-density suburban areas may be classified as high need/low provision, but it may not be the best use of limited resources to provide transit service to areas like this.

To further illustrate the literature and the problems with needs-gaps analysis, this work will review and assess from a transit planning perspective, the work of two recent studies published by Junfeng Jiao, Ph.D.

Reflective of other needs-gaps studies, Jiao and Dillivan (2013) used U.S. census block group data to measure public transit supply and compared them to the transit demand metrics of the local population. When the demand calculation exceeded the supply of transit, the census block group was labelled a 'transit desert.' Generally speaking, this means that there are more people living in a block group than the supply of transit in that block group could serve. The metaphor extended to describe transit oases where the transit supply exceeded the demand in census block groups they studied. A transit oasis, then, is a place where transit is abundant, relative to the needs/demands of the local population. How Jiao and others calculate and standardize transit demand and transit supply is discussed below.

In their endeavor to locate transit deserts and 'transit disadvantaged' populations, Jiao et al. (2013) studied transit-dependent populations who had limited access to private vehicles in order to indirectly measure equity in a transit network. Using 2010 U.S. Census data, Jiao and Dillivan's demand formula is partially derived from a 2006 Census Transportation Planning Products report by Todd Alan Steiss, a planner with Parsons Brinckeroff (Steiss, 2006).

Steiss' (2006) formula to estimate transit demand is:

1. Household Drivers = Population Age 16 and over – Persons in Group Quarters
2. Transit Dependent Population (16+ within households) = Household Drivers – Autos Available

Jiao and Dillivan (2013) use Steiss' formula and adds a third equation to it.

1. Household drivers = (population age 16 and over) – (persons living in group quarters)
2. Transit-dependent household population = (household drivers) – (vehicles available) * national level carpooling ratio
3. Transit-dependent population = (transit-dependent household population) + (population ages 12–15) + (non-institutionalized population living in group quarters)

First, Jiao and Dillivan supplement the transit-dependent household population calculation by multiplying it by the national level carpooling ratio. The national carpooling ratio, 9%, was derived from a 2013 ACS report (McKenzie, 2013). Jiao et al. (2013) then takes this calculation and determines the transit-dependent population by adding Census figures for persons aged 12-15 and non-institutionalized population living in group quarters. By adding the non-institutionalized persons living in group quarters population back into the formula, they attempt to compensate for the ‘persons living in group quarters’ calculation in step #1 Household Drivers. The formula is muddled by subtracting and adding back in the group quarters data and isolating the non-institutionalized persons in group quarters tables to calculate the transit-dependent population.

One could assume that the formula is designed to eliminate populations who cannot drive. Persons living in group quarters may include incarcerated populations and nursing home residents, but it also includes non-institutionalized populations including individuals residing in shelters, military settings, or college students residing in dormitories. Military personnel and college students may drive so it is an imperfect calculation to utilize, although Jiao et al. (2013) seem to recognize this shortcoming in step 3. The formula also assumes that anyone who is of driving age over 16 will be transit dependent if they do not have access to their own vehicle. This may be misleading in that many teenagers don’t have access to their own vehicles, and some households may carpool instead of taking transit.

It is unclear why Jiao and Dillivan use the population ages 12-15 in the formula since the specific age range of twelve to fifteen does not exist in any Census dataset – the Census age bins are ‘under 5, 5-9,10-14,15-19, etc.’ (U.S. Census Bureau, 2013). I assume that Jiao and Dillivan were trying to retrieve data for middle school aged children without drivers’ licenses who may use public transit to get to school, but it is not clear from where this data was derived.

To measure transit service (supply), Jiao and Dillivan use the following measurements:

1. number of bus and rail stops in each block group
2. frequency of service for each bus and rail stop per day (weekday service) in each block group
3. number of routes in each block group
4. length of bike routes and sidewalks (miles) in each block group

They used General Transit Feed Specifications (GTFS) data for the transit data and retrieved the sidewalk and bike data directly from the cities (Jiao J. &., 2013). Of the four cities they studied - Chicago, IL; Portland, OR, Cincinnati, OH, and Charlotte, NC – only Chicago and Portland have publicly available GIS data for sidewalk and bike route information. It is unknown where the 4th data point for Cincinnati and Charlotte, NC was retrieved from since there is no publicly available database for sidewalk data in those cities.

Finally, to be able to compare disparate numbers for supply and demand, Jiao and Dillivan standardize the demand and supply metrics by taking their z-scores (i.e., the number of standard deviations away from the mean for each data point per data set). This allows comparison of the two numerically divergent data sets. Then, Jiao and Dillivan subtracted the demand z-score and the supply z-score to get the difference ("gap") between demand and supply in each census block group in the four cities they studied (Jiao J. &., 2013). Jiao and Dillivan (2013) then compare the four cities, which have vastly different land use patterns and public transportation availability and histories. Jiao et al. (2013) write that "these four cities were chosen to include different-size cities in various geographic regions of the country and also were based on data availability" (pg. 26), but comparing Chicago, IL and Charlotte, NC may be more akin to equating horses and mules – they may be of the same genus, but they are completely different species. As with most other studies, Jiao et al. (2013) found that the areas best served by transit were in and around city-centers, with suburban areas less well served, especially in Charlotte and Cincinnati. Given Chicago's history as a city that developed prior to and around the turn of the 20th century, and Portland's environmentalist culture, it is no surprise that these two cities had the lowest rates of transit deserts and the highest rates of transit demand.

Jiao et al. (2013) writes that "the study aims to illustrate and turn the focus to neighborhoods in major cities whose transit needs are not being meet. This is useful in terms of public transit planning where new routes and stops should be located as well as how much service certain areas should receive." (Id., pg. 36) This ideology is antithetical to good transit planning. Transit planners must balance a variety of goals including ridership, social equity, access to jobs centers and other amenities, travel times, balancing land use patterns with access to transit, economic development, and budgetary restraints. Does it make for good planning to have all census block groups served with the same levels of transit? Since each block group in every American city is different, this isn't an adequate formula for transit planning. Not all census block groups are created equally. Jiao et al. (2013) acknowledges this limitation in the paper, when they write:

> "The analysis of Chicago showed a high transit dependency in the Edgewater Beach neighborhood on the far north side of the city. However, the neighborhood is known to have a satisfactory level of transit service. The reason for this lies in the study's low geographic scale. One of goals of this study was to obtain a high level of data for the smallest unit of geography possible, thus gaining the more precise knowledge of a particular area. Coupled with Chicago's high population density, block group geographies in this portion of the city are comparatively very small. While bus or train stops might only be a block away, this is not reflected in the data. Thus, certain areas that, in reality, are served well by transit, are shown as bereft of service" (pg. 37).

Census block group size skews the supply equations since smaller census block groups in Chicago may mean that the small block group does not have transit supply in Jiao & Dillivan's (2013) calculation. The demand equation does not account for population density. Certainly, living on W. Hollywood Avenue in Edgewater Beach would not be a transit burden for most individuals who would have to walk less than a block to the nearest rail station to travel throughout Chicago.

Subsequently, Jiao (2016) wrote another transit desert paper on five Texas cities – Austin, San Antonio, Houston, Dallas, and Houston. I suspect that Jiao (2016) utilized the same demand data source – the 2010 U.S. Decennial Census – that was employed in the 2013 paper, but the 2016 paper cites the use of 2012 5-year American Community Survey data. There are several shortcomings with this approach. Data on non-institutionalized populations living in group quarters is not available in the ACS, but rather is only published in the decennial census; however Dr. Jiao (2016) does not make this disclaimer in his paper, which leads the reader to assume that he used 2012 ACS 5-year data for this metric. Dr. Jiao's 2016 paper states that "census data on vehicles available are not publicly available at the block group level," (pg. 530), however I found that table B08141 "Means of Transportation to Work by Vehicles Available" is available for the 2012 5-year ACS data (U.S. Census Bureau, 2012). And as previously noted, the specific age range of twelve to fifteen does not exist in any Census dataset – the Census age bins are 'under 5, 5-9,10-14,15-19, etc.,' however, Dr. Jiao does not change the formula for his 2016 paper (U.S. Census Bureau, 2013).

In the 2016 paper, Dr. Jiao uses the following measurements for transit supply, which were derived from the respective municipalities (Jiao J. , 2016).

1. Number of transit stops within each block group
2. Frequency of transit service within each block group (based on weekday service)
3. Number of transit routes within each block group
4. Total length of sidewalks (miles) in each block group
5. Total length of bike routes (miles) in each block group
6. Total length of low speed limit roads (miles) in each block group
7. Intersection density in each block group

Similar to the methods employed in the Jiao and Dillivan (2013) paper, Jiao (2016) first divides each measure by acres to get a density value and then standardizes these disparate measures by calculating the number of standard deviations from the mean of each metric (i.e. their z-score) and then aggregates them to arrive at a single metric for transit supply in each block group. There are several drawbacks with these supply measures. Increasing the number of transit stops (in every census block group) does not mean that there will be better transit service. In fact, transit planning consultant, Jarrett Walker, recommends that "ideal stop spacing should be as far apart as possible for the sake of speed" (Walker, 2010). Walker recommends that local stops be spaced at least 400 meters apart. The number of routes in a census block group is also a problematic measurement since putting more routes through census block groups doesn't necessarily increase the quality of transit in an area. For example, if a transit agency has one route running every 15 minutes, but then replaces it with two separate routes that run every 30 minutes apart, Dr. Jiao's supply measurement would indicate that transit supply has increased and gotten better. The lived experience of transit users, however, has probably declined since they now wait longer for bus service on either route.

As I previously found, of the five Texas cities studied, only Austin, Houston, and San Antonio have publicly available data on sidewalk length (Andersen, 2018). Bike facilities data was publicly available for all five cities. GTFS data is available for the five cities' transit networks (TransitFeeds, 2018). Low-speed limit road data was available from the respective metropolitan planning organizations and intersection density can be retrieved from the Smart Location Database (U.S. EPA, 2013).

Additionally, I have concerns about adding the 'non-institutionalized persons living in groups quarters' data back into the transit-dependent population demand equation, since census block groups that include UT-Austin or Southern Methodist University in Dallas were labelled transit deserts in Jiao's research although, both areas are very well-served by transit (2016). The addition of this data appears to weight it within the transit-dependent population demand equation perhaps because it is partially present in step 1 of the data "persons living in group quarters," although it is subtracted there from the group of presumably eligible drivers ages 16 and over.

Since there are shortcomings with both the demand and supply metrics employed in both of Jiao's papers, it is challenging to crosswalk the data to replicate the studies, however, in an earlier study conducted by the author, I attempted to re-create the needs-gaps analysis of Dallas County, Texas' transit system. Figure 3 illustrates the transit deserts and oases in the region.

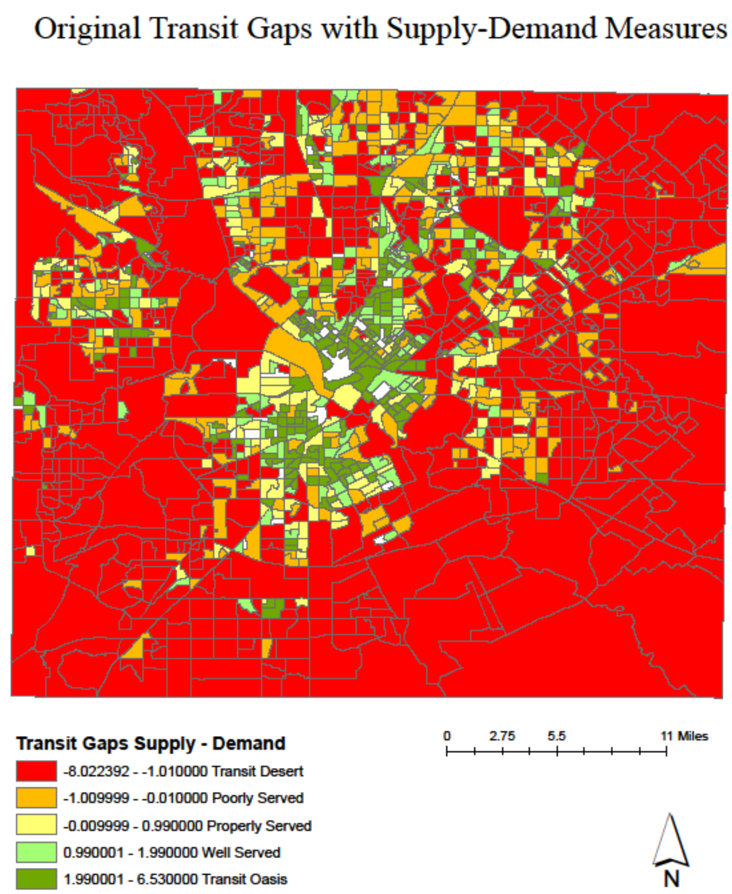

Figure 1: Original Transit Gaps map analysis replicated with supply-demand measures used in Jiao (2016) paper. Source: (Andersen 2018).

In the Jiao 2016 paper, the transit gaps research found transit deserts in outlying areas of Dallas County. In some cases, the census block groups that are ‘properly served’ have no residences nor do they have a high number of jobs. The needs-gap analyses is not context-sensitive. An example of a census block group that is ‘properly served’ in Austin, TX is the Morris Williams Golf Course in east Austin. No one lives there, and anecdotally, Austinites would report that they rarely see golfers with their signature golf bags on the bus transit system. Analytical data cannot replace the need for planners to consider land use and existing conditions when planning for transit.

Needs-gaps literature varies widely in its data, methods and prescription for application. Some researchers utilize it to illustrate equity analysis. Other researchers use it to illustrate census block group ‘gaps’ in transit service provision. But context-specific land use has not been appropriately addressed in the literature of needs-gap analysis. While transit is concerned with accessibility – including frequency, travel times, and connecting people to social, economic and cultural opportunities – it’s efficacy relies on land use, frequency and dense walkable places.

Transit planning cannot substitute this analytical approach to what are fundamentally political problems in any given region. For example, a route may serve as a life-line to a senior living facility. That facility may not be well represented in Census data – for example, a block group may represent a high proportion of 65+ population, but that block group may be a well-to-do, suburban retirement community, which may not have as much use or interest in public transit. Census data will obfuscate these important distinctions. Planning requires human judgment, funding, and political will. Data can be one tool to advance planning work, but it is not a substitute for holistic human judgment.

After interviewing professional transit planners at the Indianapolis, IN public transportation company, IndyGo, and the Dallas, TX public transit agency, Dallas Area Rapid Transit, I concluded that transit planning must be sensitive to local area conditions such as land use (Marron, 2018; Salin, 2018). Needs-gaps analyses do not respond to local area conditions and may even undermine them because supply-demand algorithms do not adequately account for the diversity of land uses. The following chapter attempts to systematically account for land use in needs-gaps analyses.

Chapter 3: Research Methods

To judge the effect of land use on needs-gaps research, this research quantifies the land use into a composite score and then calculates its effects on the needs-gaps scores to show change with the new land-use related results. By weighing land uses that may be more critical to public transit, planners may utilize land use to better understand local conditions and the need for transit.

To see how important land use is to needs-gap analysis, this research analyzes area land use conditions for public transit relevancy. I assign each relevancy values to land uses and then derive a block group land use composite score to represent the percentage of each land use per block group. Then the block group composite scores are standardized, multiplied by the demand z-scores calculated from the Andersen (2018) transit desert research, standardized again, and then incorporated into a new transit gap score (the supply z-score minus the new demand z-score). A more detailed discussion of data sources and methodology follows.

I chose to focus the land use and needs-gaps analyses in Dallas, Texas due to the availability of regional data. It is also one of the cities studied in Dr. Jiao's (2016) transit desert research. I used the North Central Texas Council of Government's 2015 Land Use GIS and 2015 TIGER Block Groups shapefiles for Dallas County to conduct my spatial analysis (NCTCOG, 2017; U.S. Census Bureau, 2018).

First, I scored the land uses in Dallas County with scores between 1-3 to each land use type with 1 representing land uses least relevant to transit use and a score of 3 representing the most relevant land use types for transit use. Table 2 illustrates the land use typologies in the NCTCOG Land Use dataset and the scores I assigned to them.

Table 2: Dallas County land uses and their assigned scores. Land use definitions were derived from NCTCOG 2015 Land Use Inventory Description (NCTCOG, 2015).

Land Use Type	Score
Single-Family - Single family detached units and duplexes	2
Multi-Family - Apartments, condominiums, residential hotels, and single family attached units	3
Mobile home - Mobile homes inside mobile home parks and freestanding units outside parks	3
Group quarters - Nursing homes, group homes, college dormitories, jails, and military base personnel quarters	3
Commercial - Unspecified office or retail uses or a combination of office and retail uses. Day care facilities are also included here.	3
Office - Generally includes any administration functions including those conducted by corporations, financial institutions, and governments.	3
Retail - Retail trade and services. Examples include department stores, repair shops, supermarkets, and restaurants	3
Hotel/Motel - Hotels, motels, and lodges	2
Institutional/semi-public - Churches, governmental facilities and offices, museums, hospitals, medical clinics, libraries, and military bases are included here	3
Education - All public and private schools including elementary schools, middle schools, high schools, colleges, universities, and vocational schools	3
Industrial - Manufacturing plants, warehouses, salvage yards, quarries, and mines	2
Utilities - Sewage treatment, water treatment, and power plants; power line easements; and pumping stations	1
Airport - Airport terminals	3
Runway - Airport runways	1
Large stadium - Large venues for organized events	3
Railroad - Railroad lines and stations and rail-to-truck transfer facilities	1
Communication - Radio, television, cable, and telephone facilities and lines	1
Transit - Passenger rail and bus lines and facilities	3
Mixed-use - Areas that contain both commercial activities, such as office or retail, along with residential uses in the same facility or as part of the same development	3
Parks/recreation - Public and private parks, golf courses, public and private tennis courts and swimming pools, and amusement parks	2

Table 2 (cont.)

Landfill - Sanitary landfills, land applications, and similar waste management facilities	1
Under construction - Land that has undergone site preparation with construction in progress.	1
Cemeteries - Dedicated burial places	1
Flood control - Major flood control structures including levies, flood channels, and dams	1
Vacant - Undeveloped land	1
Residential acreage - Land that is mostly undeveloped yet includes a mobile home, house, or other residence as a minor part of the use.	1
Ranch land - Land currently in use or suitable for breeding and raising of livestock such as cattle, horses, goats, or sheep	1
Timberland - Land covered by trees	1
Farmland - Land used for growing crops or suitable for such activities	1
Improved acreage - Land that is mostly undeveloped yet includes a non-residential structure with road access as a minor part of the use	1
Parking - Large (at least one acre) paved areas dedicated to vehicle parking including parking structures	1
Water - Lakes, rivers, and ponds of at least 10 acres are included here.	1
Small water bodies - Water bodies of less than 10 acres and fish hatcheries.	1

Since each block group often had multiple land use typologies within it, the land uses had to be clipped to fit within the block group. It was important that the land use type and corresponding score represented the spatial percentage of the block group that it constituted. Next, the composite score for each block group was calculated from the weighted scores. My calculations for deriving the composite score for transit suitability for each block group were:

1. Percentage of block group = area in acres of the land use type / the sum of total land use in acres in the block group.
2. Weighted score = score of each land use type * percentage of block group
   Weighted scores were grouped by the block group
3. Composite score = Sum of the weighted score.

This composite score was spatially sensitive as it reflects intersecting land uses within block groups and their scores. Land use composite scores are visually represented within the block groups.

Next, I calculated the standardized z-score for each land-use composite score. Because land use was not represented in the transit demand calculation in the prior transit gaps research conducted by Andersen (2018) or Jiao (2016), it is reasonable to add this calculation into the demand calculations. So, I added that land-use composite z-score to the demand z-score from the transit gaps research (Andersen, 2018). A new z-score of the aforementioned two combined demand z-scores was calculated. From there, a new gap calculation was derived by subtracting the original supply z-score from the newest z-score of the two demand measures. Figure 2 illustrates the new gap in transit supply and demand across the region. Lastly, I calculated the percentage change from the original transit gap calculation to the new transit gap calculation. Figure 3 demonstrates the percentage change between the two gap scores. The preceding method attempts to gauge the relevancy of land use to needs-gaps analysis. Land use analyses are complicated and contested, so the author does not claim that this is the only or correct method for testing the relevancy of land use to transit planning. The goal of this methodology is to illustrate the importance of land use to transit planning.

Chapter 4: Results

It should be noted that there are arbitrary elements to all analyses of this type. For example, the final score in Jiao (2016) needs-gaps analysis has a cut-off point of +6.53 or -12.9 as being served or devoid of service. These points are arbitrary. Moreover, the limited use of adding land use into the demand calculation is to demonstrate how the results of the needs-gaps analysis can change. It is not to claim absolute certainty of the analysis.

If land use were not relevant, I would not expect any significant changes after applying the land use z-score to the demand z-score, either on a tract by tract level or on a regional level. With the addition of the land use z-score, the transit gap range expands considerably from -7.15 to +24.59. Interestingly, with a wider range on both ends of the scale, there were six fewer block groups labelled transit oases, but eight more transit deserts identified with the addition of land use z-scores supplemented to the demand measure. This suggests tracts that may be of interest to transit planners.

If there were no relationship between land use and the transit gap, we would expect to see no discernable pattern in the block groups that had the most change. The changes found in the percentage change map (Figure 3) appear to be concentrated in the northern crescent of the city, with more declines in gap scores than increases. Moreover, the percentage change map in Figure 3 may suggest locations that are attractive for transit that are not reflected in the population density metric of needs-gaps analyses.

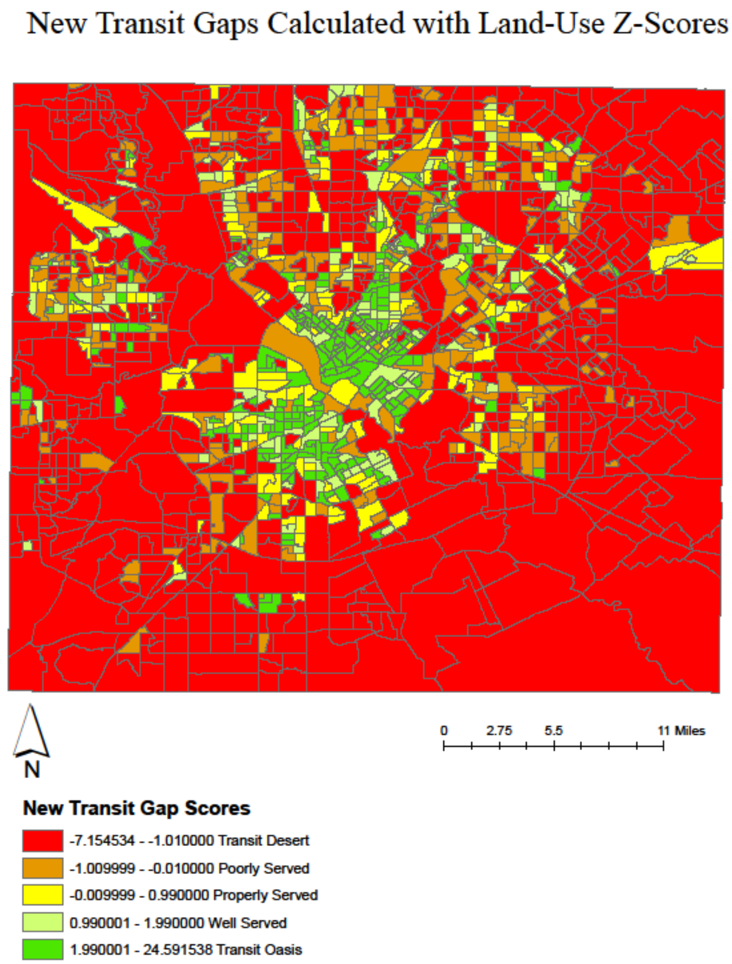

Figure 2: New Transit Gap Scores with Land-Use Composite Z-Scores added to the demand Z-Scores from the original transit gap research (Andersen 2018).

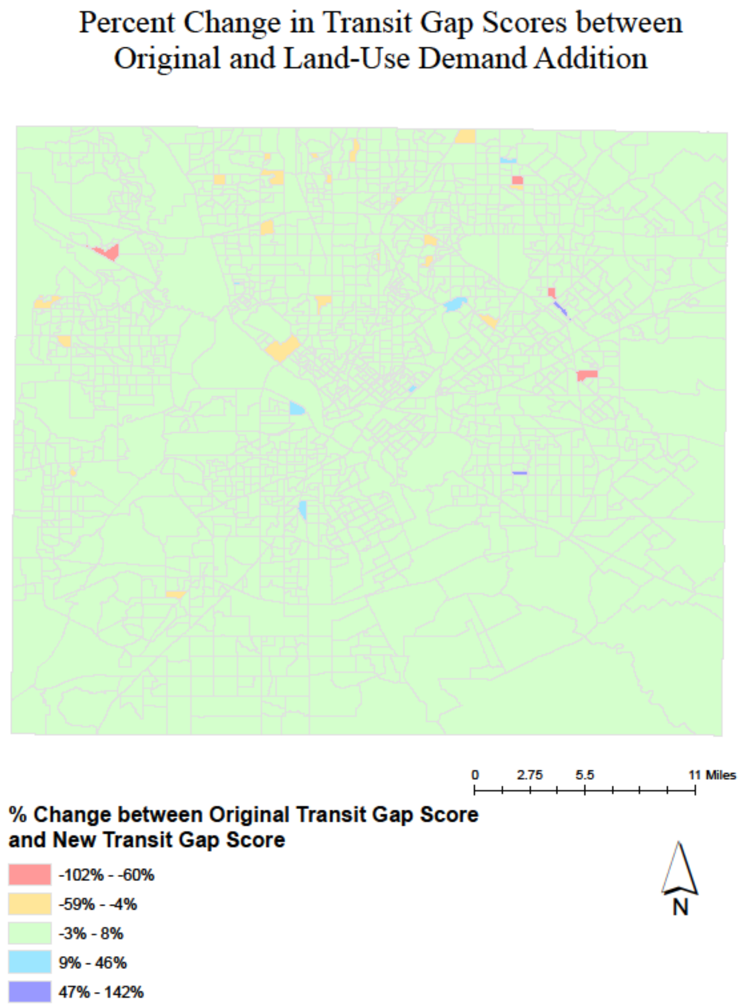

Figure 3: Percent Change from the Original Transit Gap Score (Andersen 2018) to the new Transit Gap Score with land-use added into the demand equation.

Absent the transit gaps calculations, land use is an appropriate consideration for transit demand because it is reflective of where people live, work, and access amenities across a city. It is visibly apparent where housing and employment patterns are found in a region. Furthermore, needs-gaps studies poorly account for areas that do not need transit supply. There are many block groups that have significant areas of ranchland or farmland that do not need transit.

To illustrate these holistic approaches, Figure 4 illustrates only the composite scores of land uses within the block groups across Dallas Co. for public transit provision. Generally, North Dallas has the highest concentration of transit dependency since it has a greater number of block groups with the most transit relevancy. But with nearly 86% of the county's jobs and 83% of property values found in North Dallas, economic disparity is vast between North and South Dallas (Joseph, 2017). Transit relevancy in North Dallas may be driven by greater economic resources there including factors such as commercial, office, and retail concentrations. However, skirting transit obligations to South Dallas would be unlawful (FTA, 2012). As aforementioned, transit planning block group by block group is insufficient, but this map does give a planner a general sense of which areas of the region are most suitable for transit provision.

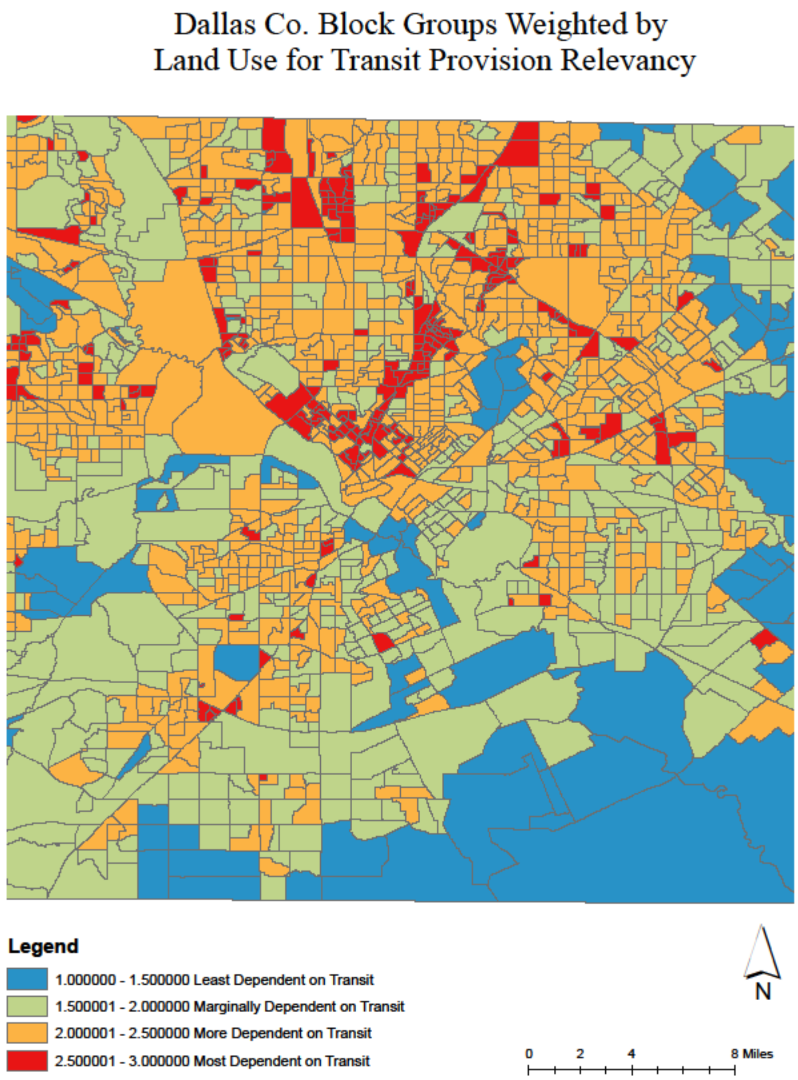

Figure 4: Map of Dallas County's Block Groups Weighted by Land Use Suitability for Transit

Figure 5 takes the composite land use scores in block groups across the county and layers the existing DART transit system onto the map (Dallas Area Rapid Transit, 2017). Like many American transit networks, DART is a hub-and-spoke design that radiates outward from downtown Dallas. Taken as a regional transit system, DART appears to largely be providing transit to the areas of the region with land uses that most reflect the need for transit. More importantly, the transit network moves through different land use intensities to provide access across the region. The transit network also appears to avoid land use areas that I coded as a 1, or those areas least dependent on transit. Since single-family housing dominates the region (see Figure 6), and it was scored as a 2, much of the orange areas that are more dependent on transit are providing transit to low-density, single family housing developments across the city. This is not unusual for an American transit system since the predominant land use type in nearly all American cities is single-family housing.

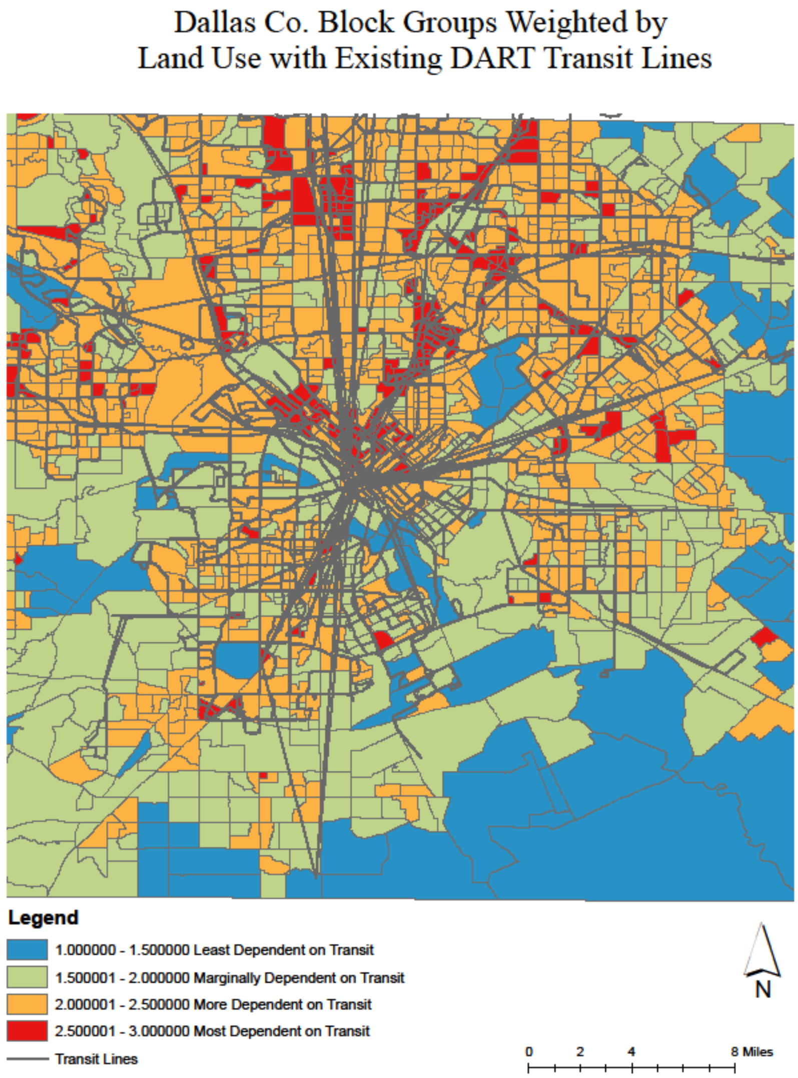

Figure 5: DART's existing transit lines appear to be serving areas of the city with land uses that reflect the greatest need for transit. Composite scores of land use relevancy for public transit were calculated for the county.

Comparing figures 5 (composite land use scores and transit) and 3 (the original, replicated transit desert map) illustrates that areas with land uses that are least dependent on transit are also labelled transit deserts in Dr. Jiao's research. Transit agencies should not bring transit to areas that include farmland, timberland, or dominant water bodies in a region. The block groups with composite scores of 1 clustered in the southeastern area of Dallas are labeled residential acreage and farmland – both represent undeveloped tracts of land. These are not land use types that need transit provision and they shouldn't be considered transit deserts since no one lives there. Therefore, this research takes a more context-sensitive approach to transit planning than needs-gaps analyses and is more relevant to the needs of transit planners.

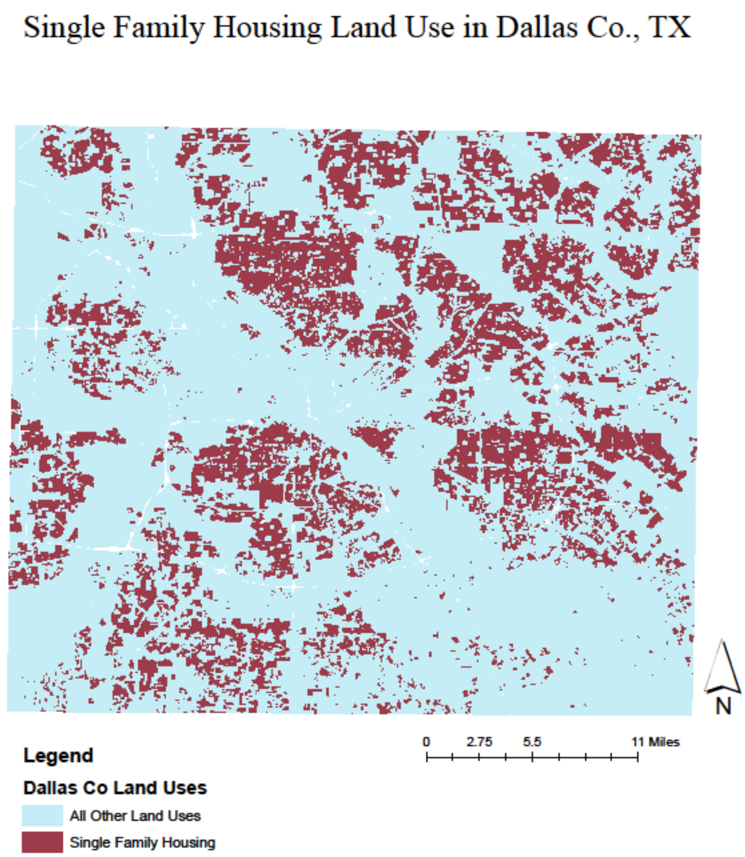

Figure 6: This map illustrates that single-family housing is the dominant land use type in Dallas Co., TX

Figure 6 illustrates that single-family housing is the dominant land use typology in Dallas County. Figure 7 approximates evaluating land uses that would encompass employment centers and other critical facilities. Since these employment clusters are spread across the region, DART's system has to rely on suburban-style transit service planning – moving households from low-density single-family suburbs to clusters of employment centers predominately in the northern half of the city.

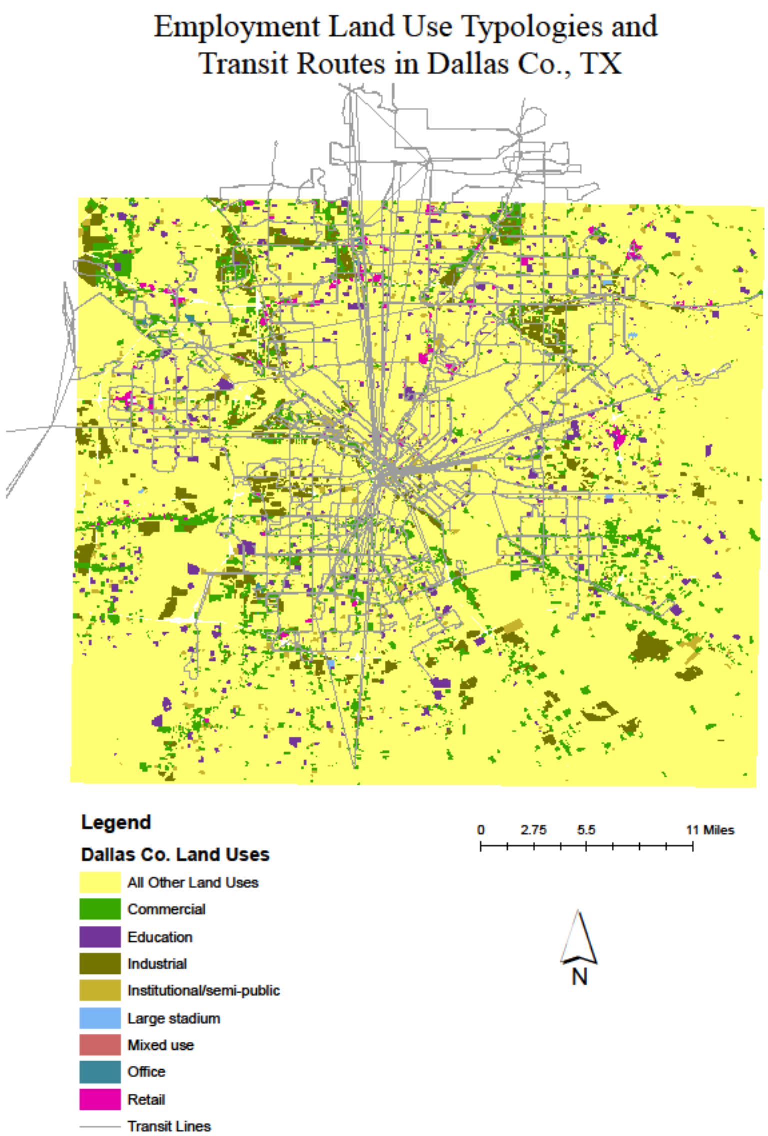

Figure 7: Employment land use typologies and transit lines in Dallas County, TX.

Chapter 5: Discussion and Recommendations

This analysis layers land use into a demand calculation for needs-gaps analysis in Dallas, Texas. Since land use does not significantly affect the transit gap score, it's inclusion with the demand z-score suggests that land use, to a certain extent, is factored into the needs-gaps analysis through population density scores. Arguably it is the gaps between the new and old supply-demand maps that could suggest areas that are in need of service or attention. For example, there could be an area with dense commercial uses that did not have a high population density. This area may drive transit demand in the new model but would not drive transit demand in the old model.

This analysis takes a transit system-wide approach by including land use as a tool for transit planning. By using block groups as building blocks for the region rather than the unit of analysis, this research should be taken as a whole rather than its parts. Since American zoning designations are usually clustered, area land uses are found in proximity to each other.

It appears that the existing DART system is reflective of land use typologies that require transit service, although the dominance of low-density single family housing in the region makes the system much more inefficient. The DART system appears to be moving households from single-family housing land uses to employment center clustered across the northern portion of the city. This methodology does account for some critical facilities in the region (hospitals, employment centers, educational facilities, etc.), although it would require human judgment and knowledge of those facilities to do the best transit planning for the region.

This methodology of analyzing land use provides a more relevant approach to transit planning than analyzing supply-demand measures to identify transit gaps. Since there are many land use typologies that would not require transit service, but are simultaneously labelled 'transit gaps,' this methodology takes a more context-sensitive approach to transit planning.

This methodology may supplement transit planning in a region since it is regional in its scope. Unlike needs-gaps analyses, which use block groups as the unit of analysis for concluding if it is a stand-alone transit desert or oasis, this method uses block groups to examine the land use conditions for the entire region.

Land use designations do account for a measure of density through the coding of multifamily housing, although Census data could provide more accurate density measurements. Because density matters a great deal for good transit service, it must begin with better land use planning across Dallas and other American cities. Superb transit service will follow.

By removing Census data from the analysis, equity planning is foregone with the land use analysis methodology used here. Oblique measures like coding multifamily housing and mobile homes with the highest scores may provide some measure of transit planning for lower-income households, but it is imperfect and inaccurate. It should not be misconstrued as a methodology for equity analysis.

This methodology only examines the needs-gaps model for transit service in Dallas County, while other factors such as frequency, decreasing travel times, and appropriate coverage are all part of the ingredients that make for a superior transit soup in order to increase ridership across a region. Conducting origin-destination analyses on household workers could also help to illuminate more micro-level data for accessibility amongst workers in a region.

Chapter 6: Conclusion

Public transit service planning is beholden to many factors including route design, frequency, and appropriate coverage for a region. Its primary objective is to move people from their households to a destination including workplaces, shopping, childcare, educational and medical facilities. Because land use is intrinsic to those origins and destinations, this professional report examines land use suitability, needs-gaps measures, and transit relevancy in Dallas County, TX. Public transit does just serve stand-alone block-groups or other spatial units of analysis, but rather it operates across an entire region. Labelling individual block groups as transit deserts or transit oases does not provide transit planners with a context-sensitive approach to planning for a system. Since similar land uses and zoning types are usually found in proximity to each other, examining land use can better aid the transit planner in assessing area trends for transit planning.

This methodology should be layered with additional research measurements including density measures for appropriate coverage, workplace destinations with household employment data, frequency for increasing ridership, and evaluating equity measurements in order to comply with FTA rules (Marron, 2018).

Lastly, examining land use patterns can aid transit planners to work in concert with land use planners to help shape improved land use for a region because denser land use will usher in better transit service.

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